

FY08 FATE Proposal

Project Title:

Developing Statistically Robust IPCC Climate Model Products for Estuarine-dependent and Anadromous Fish Stock Assessments

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1. Background

As the reality of global climate change attains scientific and public consensus and its physical signals become quantifiable, the focus is turning to describing and forecasting its future impacts of most importance to society. Ecosystem goods and services, the economic, social, and intrinsic benefits derived from ecosystems, are of special concern. The California Current large marine ecosystem (CCLME), a region of high biological productivity and valuable fisheries, and its populations have shown a strong sensitivity to past climate variability (Baumgartner et al., 1992; Mantua et al., 1997; Peterson and Schwing, 2000) and are expected to be particularly impacted by future climate change and human activities to mitigate its impacts on other sectors (Lindley et al., 2007; Ralston, 2005). An ecosystem-based management approach will require reliable stock assessment models that provide robust long-term (10-50 year) projections of population abundance.

Providing quantitative estimates of the magnitude and uncertainty of future climate change of US marine ecosystem of interest to fisheries management, and the character (e.g., frequency distribution, extrema, phenology) of the large natural variability known to influence these systems and their populations, is a major priority. A limitation to this has been a lack of dependable regional climate projections of the forces that drive ecosystem processes. The key resource is the recently available output from 23 state-of-the art coupled atmosphere-ocean climate models that are part of the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4). While of great potential use, it is uncertain how these IPCC model results can be validated, selected and used on a regional basis, and made ecosystem-relevant products, given their spatial resolution and model-to-model differences.

The goals of this project are to develop objective methods for combining the outputs of the AR4 models at the regional scale for selected output variables to construct (probabilistic) indicators of future climate change, and to use these indicators in existing stock assessment models to project abundances for the next several decades. From these models, we will be able to produce probabilistic assessments for effective long-term policies and management decisions under a reasonable range of climate change scenarios. Quantifying the likely direct impacts of future climate change will also allow management to compare decision scenarios incorporating other human stressors on these populations, such as overfishing, urbanization, stream and estuarine

habitat modification, and western US water resource reallocations, in the context of future climate states.

This proposal responds directly to the first type requested by the FATE RFP, “to support collaborations between ecologists or oceanographers and scientists actively engaged in agency stock assessments with a goal of improving stock assessments through use of FATE indices.” Specifically, the project will provide indicators of future climate state for forcing west coast stock assessment models, and begin to provide to resource managers the kind of information needed to evaluate climate change considerations in the context of other ecosystem stressors (e.g., overfishing, water allocations).

2. Approach

The project has two principal tasks: (1) develop a set of rules for objectively evaluating and averaging climate model projections, and use them to develop probabilistic estimates of the future state of the CCLME; and (2) produce leading indicators of fishery-relevant climate parameters, and incorporate these indicators into selected stock assessment models to project future abundance tendencies under realistic climate scenarios.

2.1 Evaluating climate models and developing indicators

The first task is to develop statistically rigorous rules for evaluating, selecting and combining the results from the AR4 models and apply them to the CCLME and the freshwater and estuarine systems that feed into it. These methodologies will allow indicators of climate change to be determined objectively for the CCLME. They will also have wider application to other US and international LMEs, as well as contribute toward developing protocols for the next IPCC Report.

We propose to use both hierarchical Bayesian methods as well as multivariate state-space models to blend the information from the different GCMs to produce probability density functions of desired parameters. We will consider variables like coastal upwelling, ocean transport, ocean, river and land surface temperatures, precipitation, and discharge, and provide probability density functions and modal estimates of summaries of the spatial variability of such quantities, as predicted by the model ensembles.

The AR4 coupled General Circulation Models (GCMs) are much improved from the Third Assessment Report of six years ago, with better spatial resolution and topography, interactive land processes, and ocean and cloud physics. More than half of the models are able to capture the natural climate variability when the models are compared to 20th century data (Wang et al. 2007, Overland and Wang 2007). Because of a CO₂ lag effect, the largest uncertainties in future climate projections out to 2050 of relevance to fisheries and ecosystem management are from model to model differences rather than emissions scenarios.

IPCC AR4 models have the potential application for describing future variability relevant to fisheries management over regional scales (Overland and Wang 2007). This conclusion is based on model improvements, comparison with data, the large community involvement in AR4, and the modeling of key climate processes. However, there are a number of outliers among the group of models compared to 20th century data on a regional basis, so development of selection or

averaging rules is critical to constrain uncertainty in future projections and reduce the likelihood of indices based of spurious climate model results.

Hierarchical Bayesian analysis allows for the investigation of the modeling uncertainties affecting the size of the expected changes in the climate (Tebaldi et al., 2004, 2005; Smith et al., 2007; Tebaldi and Sanso, 2007). These methods consist of statistical models that blend the information from the different GCMs using hierarchical structures. The results can be expressed as probability density functions for model variables for large regions on yearly or seasonal time scales.

In the present work, we will extend the hierarchical modeling methodology to account for spatial variability, which will be useful in isolating differences in specific watersheds or regional ecosystem. We will use methods based on process convolutions (Lemos and Sanso, 2006), which have the advantage of providing enough flexibility to capture non-homogeneous spatial correlations. Moreover, they can be naturally embedded in a state-space model to consider time-varying evolutions. These will be used to study and blend fishery-relevant parameters from the CCLME, both the ocean habitat and some of the watersheds and estuaries that feed into it.

We will also apply state-space modeling and related statistical methods to identify the principal spatial patterns of variability in output fields from the IPCC AR4 models and to compare these fields with historical observational data. We have previously applied state-space and subspace identification techniques to describe dominant modes of variability at different time-scales. These methods allow us to estimate common nonparametric trends, common stochastic (changing) seasonal patterns, and common stochastic (stationary) cycles in the data. The models also can be run in forecast mode, can provide a true likelihood for statistical analysis, and can be used to analyze for structural breaks in the data and the type of break, as well as clustering of the estimates based both on the smoothed observed and estimated unobserved components.

State-space models have been applied to retrospective analyses of ocean temperature in the North Pacific and on a number of familiar climate indices (Bessey and Mendelssohn, 2007; Mendelssohn and Schwing, 2002; Mendelssohn et al., 2003, 2004, 2005; Mendelssohn and Bessey, 2007; Palacios et al., 2004). These analyses have shown that the north Pacific during the 20th century was characterized by a set of well-defined spatial and temporal patterns that suggest natural and anthropogenic mechanisms as their source (Fig. 1). One striking result is that the accelerating trend toward Arctic sea ice loss in the latter half of the previous century corresponds to trends identified in the tropical and extratropical Pacific (Mendelssohn and Bessey, 2007), a pattern captured by some, but not all IPCC models (Fig. 2).

We will examine a number of output variables with the greatest potential to be ecologically-relevant climate indicators, including the variables described above. An initial analysis will be performed on IPCC hindcast ocean temperatures (SST and subsurface) for the 20th century, to compare historical and projected spatial patterns and temporal trends (cf. Overland and Wang, 2007). These will be compared with an identical analysis of observed and reanalysis temperatures to test GCM validity further. Similar analyses of other fields from hindcast and 21st century projections will explore their patterns and relationships. Stock assessment models can be run with the 20th century parameters to compare with the 21st century projections and check the validity of the models and indices.

2.2. Selecting indicators and incorporating into stock assessment models

A second task is to use these methods to prudently select the appropriate climate model projections and variables for developing ecosystem indicators. These indicators can be tested to investigate how well they explain variance in the abundance of marine populations, and used in stock assessment models to project their long-term tendencies. We will not use these models to produce a pure “forecast” time series of future abundance, but to develop via multiple runs a probability function of abundance under likely future climate scenarios, based on the indicators developed from the IPCC GCMs.

We will gather existing data on the abundance of group of west coast fish, and explore the relationships between abundance and the watershed and ocean indicators, using the state-space methods described above. Our focus will be on estuarine-dependent and anadromous species, because of their strong response to terrestrial and freshwater conditions, which for the CCLME are likely to be greatly impacted by future climate change as well as other human activities to mitigate the impacts of change (e.g., water resource allocations, habitat modification in response to sea level rise and changing precipitation and streamflow patterns).

Candidate species include those managed by the Pacific Fisheries Management Council (PFMC), notably starry flounder (*Platichthys stellatus*), chinook salmon (*Oncorhynchus tshawytscha*), Pacific herring (*Clupea harengus pallasii*), and northern anchovy (*Engraulis mordax*). Most of these species use San Francisco Bay as a habitat, while chinook utilize numerous watersheds along the west coast. The starry flounder stock assessment model provides a particularly good test case for including watershed indicators into a stock assessment. Summertime abundance of young-of-the-year starry flounder in San Francisco Bay is closely related to discharge into the bay during the previous winter (Ralston, 2005), and the PFMC stock assessment model is currently being modified to incorporate watershed parameters.

3. Benefits

This project will be a starting point for understanding climate-ecosystem interactions, by beginning the dialog between climate and fisheries scientists on incorporating future climate change scenarios into long-term (10 years and longer) management of commercially important fish stocks and their ecosystems. Many are being rebuilt or are threatened, a status that can be further imperiled by changing ocean conditions associated with global climate change.

This project will provide a set of rules or methods for evaluating, selecting and combining the results from global climate forecast models to create probability density functions for model variables for fishery-relevant regions on yearly or seasonal time scales. We will also validate 21st century projections of climate by comparing ecologically-relevant climate variables from the GCMs to the patterns and relationships in historical observations and model output from the 20th century.

This project will supply a new set of indicators of past and projected physical climate state and benefit stock assessment models that incorporate climate variability as drivers on the space and time scales appropriate for assessing population abundance. These will be openly available for fishery and ecosystem assessments.

Finally, this project will begin to provide to NOAA resource managers the kind of information needed to bring climate change considerations into decisions that up until now have ignored this potentially overriding issue (e.g., relicensing water projects, rebuilding plans for fisheries).

4. Deliverables

YEAR 1 (July 2008 – June 2009)

1. Estimate state-space models and common trends, seasonals and cycles from output from selected climate models.
2. Apply the hierarchical modeling methodology to average fields for physical climate parameters. Develop the methods to extend the analysis to spatial fields. This includes the formulation of appropriate hierarchical random field models, development and codification of numerical methods to fit the data and testing using subsets of the data.
3. Based on stock assessment model development and analysis, select appropriate parameters, and time and space averaging scales, for developing indices.

YEAR 2 (July 2009 – June 2010)

1. Apply the methods developed in Year 1 to the full data set, including other variables deemed important to the modeling effort. Consider possible extensions to models that consider more than one variable.
2. Develop leading climate indices for forcing stock assessment models, and make them publicly available through FATE web page.
3. Run projections of stock assessment models with IPCC indices and develop probability functions of abundance projections.
4. Complete two peer-reviewed publications describing research results.

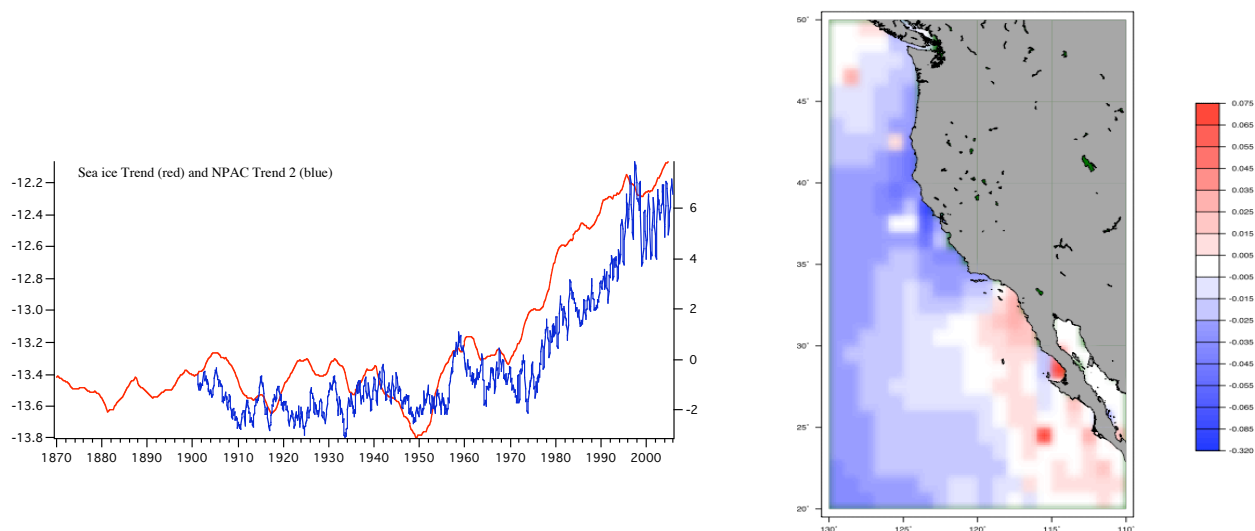


Figure 1. Results from common factor analysis of CCLME SST, showing time series (left panel, blue line) and spatial loadings of one of the leading modes of SST variability. Areas shaded red (blue) in right panel show a warming (cooling) tendency in this mode, highlighting regional responses within the CCLME to a global warming trend. The red series on left is the area of Arctic ice coverage, inverted for comparison. The analysis indicates a strong correspondence between SST change in the CCLME and Arctic sea ice, indicative of global climate forcing.

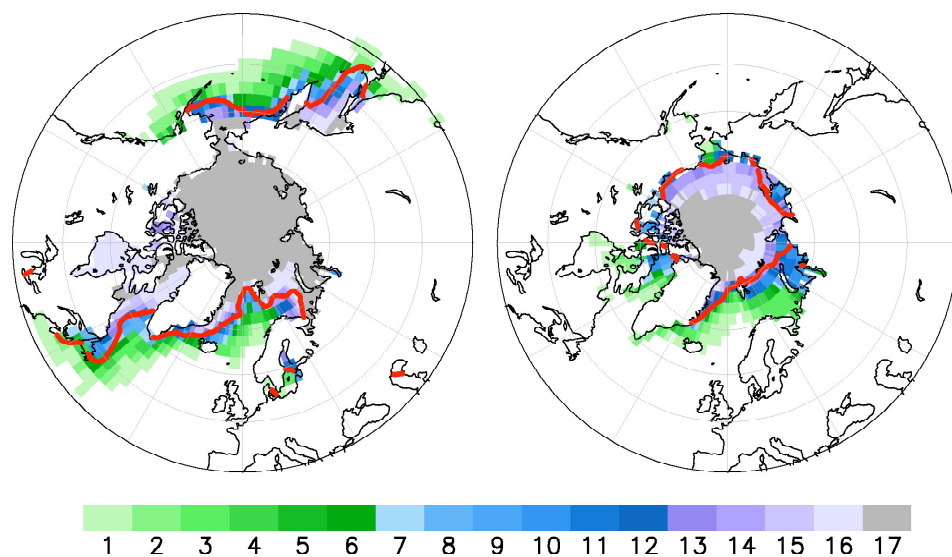


Figure 2. Sea ice in 17 IPCC AR4 models compared to recent data (red line) for March (Left) and September (Right). The colors indicate how many models have ice this far south. Note that about 5 of the models have considerably too much ice in the Pacific and west Atlantic winter. The Barents Sea has a large percentage of models that have too much ice in both seasons. Such models should be considered as outliers, when evaluating regional projections, such as sea ice in the Bering Sea.

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